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(56) Documents Cited
GB 2297432 A GB 1053838 A SU 000608205 A
Y A Bashkirov et al, IEEE Transactions on Applied Superconductivity, Vol 5, No 2, June 1995, pp1075-1078, "Application of Superconducting Shields in Current-Limiting and Special-Purpose Transformers"

(58) Field of Search
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(54) Abstract Title
Transformer with a superconducitve current-limiting arangement

(57) A transformer arrangement comprises a ferrous core 1 with two conductive windings 6, 7, 10 at least one of which is super-conducting. The windings 6, 7, 10 are wound on said core 1 with one winding having two parts 6, 7 wound on different parts of the core 2, 3 in series opposition. One of said winding parts 7 includes a super-conducting shield 8. The winding part 7 and the shield 8 are arranged to provide a current-limiting effect on over-current conditions. Either of the windings may be made of a conventional electrically conductive material (e.g. copper or aluminium). The transformer provides an electrical energy transfer interface which may be used between physically separate cables in which one of the cables is a conventional conductive cable and the other a superconductive cable or both cables may be superconductive. The core 1 may have three limbs and the shield 8 may be a cylindrical shape and may be driven into a resistive state by a coil formed around the cylinder.

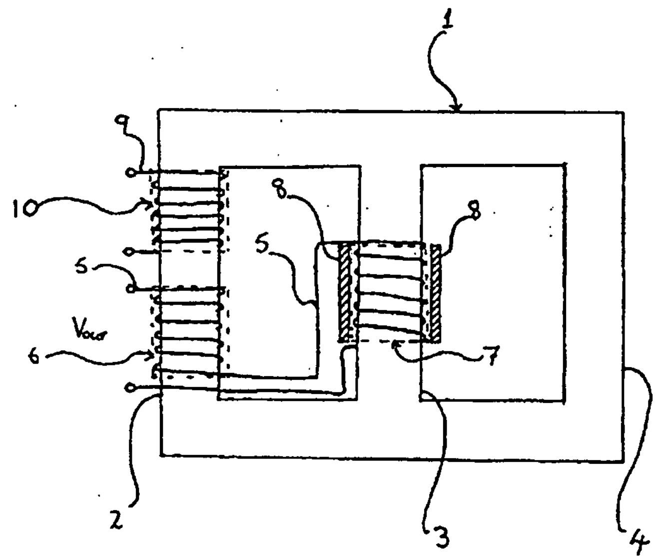

FIG. 1

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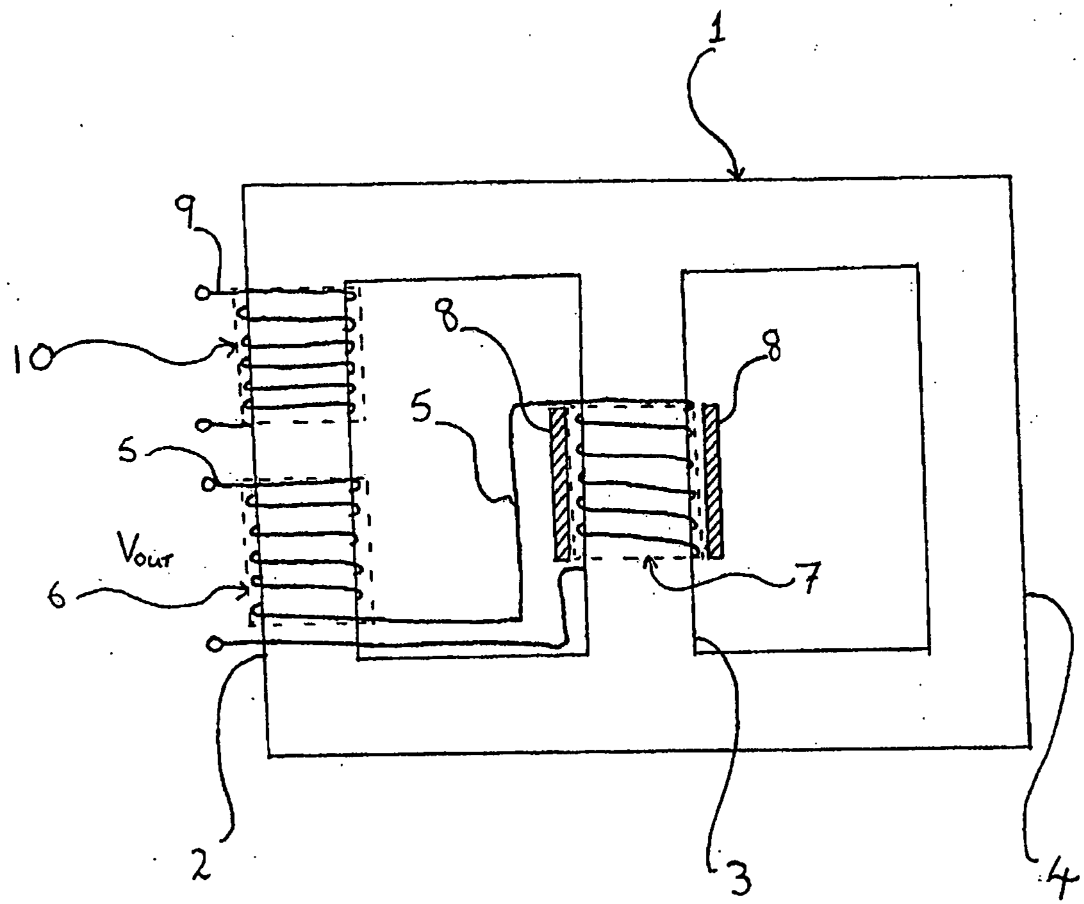

FIG. 1

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ELECTRIC POWER TRANSFER MEANS

This invention relates to means for transferring electric power between a superconducting cable and another cable in a single phase or multiphase system.

Superconducting power transmission cables are presently being developed. Problems may be encountered in connecting such a cable to a conventional cable or wire at ambient temperature. Such connection may result in a heat load being introduced from the conventional cable into a cryostat which is used to cool the superconducting cable. Another problem which may be encountered with superconducting cable is that, should a fault occur which causes an excessive current to flow, the superconducting cable may revert to the normal conducting state and the current overload may cause burn-out.

The invention provides means for transferring electric power between two cables, one of which is superconducting, the means comprising a ferrous core, a first electric conductor being wound on a first part thereof and on a second part thereof in series opposition, a portion of the conductor on the second part of the core being associated with a superconducting shield which affects magnetic flux linkage between said portion and said core, the first conductor on the first part being connectable to the first cable, and a second electric conductor being wound on the core, the second conductor being connectable to the second cable, one of the conductors being superconducting.

The absence of direct physical contact between the superconducting cable and the other

cable means that each can be thermally isolated from the other. The invention also acts as a fault-current limiter which can protect the superconducting cable from current overload. A fault-current limiter of this type is described in a paper by Yu.A.Bashkirov et. al; "Application of Superconducting Shields in Current-Limiting and Special-Purpose Transformers" (IEEE Transactions on Applied Superconductivity, Vol. 5, No. 2, June 1995), but in this paper the windings and cables are not superconducting.

By winding the first conductor on the second part of the core, such that it is in series opposition to the first conductor wound on the first part, ensures that an e.m.f. which may be induced in the winding on the second part negates partially the e.m.f. induced in the winding on the first part.

Preferably, the first conductor and the first cable are superconducting and the other conductor and the other cable are copper, which is the conventionally-used material for electric power cables. In this embodiment the superconducting cable is protected from current overload.

The core preferably comprises a plurality of parts, each in the form of a limb, onto which the conductors are wound. A third limb may be provided to complete the magnetic circuit.

The invention will now be described, by way of example, with reference to the

accompanying drawing, Figure 1, which is a schematic diagram of electric power transfer means constructed according to the invention.

Referring to Figure 1, a core indicated generally by the reference numeral 1 is shown, having three ferrous limbs 2, 3 and 4. A superconductor 5 is wound on both the first limb 2 and the second limb 3 in the same direction, ie. wound either clockwise or anti-clockwise on both limbs 2 and 3, although they could also be wound in the opposite direction to each other with the connections shown in Figure 1 reversed. The winding 6 on the first limb and the winding 7 on the second limb are said to be in series opposition, that is to say, the windings 6 and 7 are connected in series such that an e.m.f. induced in winding 6 by magnetic flux in limb 2 is at least partially cancelled by an e.m.f. which may be induced in winding 7 by flux in limb 3. The windings 6 and 7 would not normally have the same number of turns, as the number of turns in the supplementary winding 7 depends on the level of current-limiting required and on the magnetic state of the iron.

The winding 7 is at least partially enclosed by a cylindrical superconducting shield 8 which is short-circuited. The shield 8 may be made up from a single cylinder, a number of co-axial cylinders, a number of disks in parallel (Patent Application No. GB 9501717.4) or a number of turns of wire joined at its ends. Since a superconductor subject to alternating induced currents can have an extremely low resistance, shield 8 may be regarded as forming an almost perfect short-circuit (there is no load associated with the winding). The shield is typically made from low temperature superconductor,

LTS (critical temperature, $T_c \leq 25K$) or high temperature superconductor, HTS ($T_c \geq 25K$).

Cryostats or a cryostat surround the superconductor 5 and windings 6 and 7 and shield 8 at a sufficiently low temperature, thereby maintaining them in the superconducting state (typical temperatures: LTS, 4.2K or less; HTS, 77K or less).

A conventional conductor 9, which is typically copper, is wound on the first core 2 in the same sense as winding 6. The free ends of conductor 9 may be connected to a conventional power transmission cable or power source (not shown). The free ends of superconductor 5 may be connected to a superconducting power transmission cable (also not shown).

In operation, the winding 10, which comprises the conventional conductor 9, is energised by an a.c. supply from the conventional power transmission cable. The e.m.f. applied to winding 10 produces an alternating magnetic flux in limb 2 which, in turn, generates an alternating voltage across superconducting winding 6. Ordinarily, the magnetic flux would also pass through limb 3 and consequently would generate a voltage in winding 7. However, the superconducting shield 8 is arranged to produce a circulating current which generates magnetic flux in core 3 sufficient to cancel the flux produced by winding 10. Thus, practically no e.m.f. is induced in winding 7. In this situation, limb 4 completes the magnetic circuit. The output V_{OUT}, of the power transfer means is taken from the free ends of superconductor 5, and is given by the

equation

$$V_{OUT} = V_6 - V_7$$

where V_6 is the voltage across winding 6 and V_7 is the voltage across winding 7. In this case, practically no e.m.f. is produced in winding 7, so $V_7 \approx 0$ and the output voltage is that generated by winding 6. In this manner, power is conveniently transferred between a conventional power cable and a superconducting cable via conventional conductor 9 and superconductor 5.

In certain circumstances, such as a line to ground, line to line or line to neutral short-circuit fault may occur, causing a larger than normal current to flow through winding 6. This is undesirable, as a sufficiently large current can cause a superconductor to revert to its normal conducting state and the excessive current may cause burn-out of the superconducting cable.

The fault-current flowing through winding 6 also flows through winding 7. The growth of current in winding 7 produces a sharply increasing magnetic field on the surface of shield 8. Such an increase drives shield 8 into the resistive state. Thus, the shield no longer completely negates the flux induced in core 3. This flux induces an e.m.f. in winding 7, the e.m.f. increasing with increasing fault-current. Therefore, the output voltage ($V_6 - V_7$) decreases with increasing current and the fault-current is reduced to a predetermined level.

The invention may also be used to protect the superconducting cable against the loss

of superconductivity caused by an excessive temperature rise above the critical temperature (T_c) of the superconductor. When superconductivity is lost and a normal resistive state prevails, the superconductor is said to quench.

Such a temperature rise can be caused by a loss of coolant cryogen, an increase of magnetic field, a rapid rate of change of magnetic field or by excessive current flowing in the cable.

A number of techniques may be used to detect a region in the superconducting cable where a quench has occurred, for example by detecting an increase in temperature, voltage or mechanical stress. For long superconducting cables, fibre-optic cables may be used as distributed temperature sensors.

The sensors are coupled electronically to a very fast switch, for instance a gated thyristor, which, when closed, allows a large current from a current source to flow. This current may be a.c. or d.c. and is made to flow directly through the superconducting shield, or through an additional coil surrounding the superconducting shield. The additional coil may be superconducting or may be made from a normal metal conductor. The magnitude of the current flowing through the shield, or the amp turns per metre of the coil, will be such as to drive the superconducting shield into the resistive state.

When in the resistive state, the output voltage (V_6 - V_7) will decrease as described

above. Following this reduction of output voltage, a mains circuit breaker can be arranged to open and to disconnect the power supply after, for example, three electrical cycles of the supply voltage.

Variations may be made without departing from the scope of the invention. For instance, the windings shown in Figure 1 have the same number of turns. However, the number of turns for each winding may be varied to permit the voltage or current of the incoming power to be altered to the requirements for the superconducting cable. Another variation is that the conductor 9 and winding 10 need not be copper. Any conventional electrically conducting material, eg. aluminium, may be used. In addition, the conductors could be interchanged such that winding 10 is superconducting and windings 6 and 7 are conventional conductors. Such an arrangement permits the transference of electric power from a superconducting power transmission cable to a conventional cable. Furthermore, the superconducting shield 8 need not be a cylinder; it could be replaced by superconducting discs, which are described in our co-pending patent application No. 9501717.4.

Further variations will be apparent to those skilled in the art.

CLAIMS

1. Means for transferring electric power between two cables, one of which is superconducting, the means comprising a ferrous core, a first electric conductor being wound on a first part thereof and on a second part thereof in series opposition, a portion of the conductor on the second part of the core being associated with a superconducting shield which affects magnetic flux linkage between said portion and said core, the first conductor on the first part being connectable to the first cable, and a second electric conductor being wound on the core, the second conductor being connectable to the second cable, one of the conductors being superconducting.

2. Means as claimed in claim 1, in which the first conductor and the first cable are superconducting.

3. Means as claimed in claim 2, in which the second conductor and the second cable are copper.

4. Means as claimed in claim 1, in which the second conductor and the second cable are superconducting.

5. Means as claimed in claim 4, in which the first conductor and the first cable are copper.

6. Means as claimed in claim 2, in which the second conductor and the second cable are superconducting.

7. Means as claimed in any preceding claim, in which the ferrous core is provided with a plurality of limbs, the first and second conductors being wound on a common first limb, and said portion of the first conductor being wound on a second limb.

8. Means as claimed in any preceding claim, in which the core has a third limb.

9. Means as claimed in any preceding claim, in which the shield comprises a superconducting cylinder.

10. Means as claimed in any preceding claim and wherein a cryostat or cryostats are provided.

11. Means as claimed in claim 1, also having a circuit capable of driving the shield into a resistive state.

12. Means as claimed in claim 11, in which the circuit includes a coil wound around the shield.

13. Means for transferring electric power between two cables, one of which is superconducting, substantially as hereinbefore described with reference to, or as

illustrated in , the accompanying drawing.

14. An electric circuit incorporating means as claimed in any one of claims 1 to 13.

Application No:	GB 9700483.2	**Examiner:**	John Watt
Claims searched:	1 - 14	**Date of search:**	17 March 1997

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): H1T (T1C, T1F, T5, T9, T11, T12, T7C1A, T7C1B3, T7C7D); H2H (HAL, HAM, HAPA)

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Other: Online: WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
Y	GB 2297432 A (GEC ALSTHOM) see figures 1 & 2a and page 3, line 3 to page 4, line 1	1 at least
Y	GB 1053838 (LICENTIA) see whole document	1 at least
Y	SU 0608205 A (POWER RES. INST.) see figure	1 at least
Y	Y A Bashkirov et al, IEEE Transactions on Applied Superconductivity, Vol 5, No 2, June 1995, pp1075-1078, "Application of Superconducting Shields in Current-Limiting and Special-Purpose Transformers"	1 at least

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.